STAGGERED ROW FOCAL PLANE ARRAY ANALYSIS

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Georgia Institute of Technology

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Authors

A. Register and A. Henshaw

COMPUTER ENGINEERING RESEARCH LABORATORY

Georgia Institute of Technology

Atlanta, Georgia 30332-0540

Eugene L. Sanders
USASDC
Contract Monitor

Cecil O. Alford
Georgia Tech
Project Director

STAGGERED ROW FOCAL PLANE ARRAY ANALYSIS

A. Register and A. Henshaw

Abstract: The geometric features of a variety of focal plane arrays (FPA) are presented. A geometric figure-of-merit is developed and is computed for a variety of geometries. Geometrical mapping functions to transform the geometry of staggered FPAs into a non-staggered geometry are developed. The mapping functions are separable into even and odd row processes. Two preliminary analyses are performed. The first is a worst case analysis based on an object size approximately equal to one picture element (pixel). The second is a more realistic analysis based on blur-spot assumptions.

1.0 BACKGROUND

The Georgia Institute of Technology (Ga. Tech) is developing a set of application specific integrated circuits (ASIC) to perform the signal processing functions required in an exo/endo atmospheric interceptor (GBI, GBI-X, E^2I, LEAP, etc.). The ASIC signal processor (SP) was designed assuming a non-staggered or uniform 128×128 staring FPA. Some researchers in the seeker community are studying the use of staggered pixel geometries for the FPA. The staggered FPAs offer improved signal to noise ratio (SNR) for small objects. This is important for long range acquisition.

This report examines the methods and trade-offs for interfacing a staggered FPA with the Ga. Tech SP. The examination begins by attempting to derive a comparable figure-of-merit for any geometry. This figure-of-merit is calculated for the geometries known to be under consideration for the FPA. A variety of mapping functions are presented and compared. Most of these mappings must be applied before the pixels enter the SP. One promising map is a post-processed map that acts on the object centroids This map is attractive because it can be computed in the object processing (OP) portion of the seeker.

2.0 FIGURE-OF-MERIT

Inherent in the discrimination of objects is a clustering operation. The clustering operation involves a pixel and all immediate neighbors of that pixel. This clustering region is called a *neighborhood.* The relative size of the neighborhood determines the figure-of-merit. In more precise terminology, the figure-of-merit is the normalized, distance weighted, area. This measure is a normalized moment. The true moment can be calculated using,

$$Moment = \int_0^{2\pi} \int_0^{r_n} r^2 \, dr \, dq \,, \qquad (2.1)$$

where r_n is the radius from the center of the target pixel to the perimeter of the neighborhood.

The true moment cannot be used directly due to its dependence on the size or area of the neighborhood. To be useful as a figure-of-merit, the true moment must be normalized. By using the area and the moment of an equal area circle, a figure-of-merit that is comparable across geometries can be calculated. The normalized moment is given by,

$$Figure\text{-}of\text{-}Merit = \frac{2\, r_0}{3{*}Moment} \,, \qquad (2.2)$$

where r_0 is the radius of a circle with the same area as the neighborhood. When comparing different geometries, the geometry with the larger figure-of-merit will have better resolution and a lower tendency to merge two objects during a clustering operation.

3.0 PIXEL GEOMETRIES

There are four geometries that will be investigated. These four are non-staggered (baseline), regular hexagonal, stretched hexagonal and staggered square. There are three measures that will be important in understanding each of the geometries. The three measures are cluster area, aspect ratio and figure-of-merit.

The cluster area is the true area of the neighborhood. The aspect ratio is a ratio of the normalized distance between pixel centers, horizontal and vertical respectively. The reported aspect ratio will be formatted 'horizontal distance:vertical distance'. Consider an FPA with an equal number of columns and rows. If the aspect ratio is 1:1, the FPA is square. If the aspect ratio is not 1:1, the FPA will be rectangular. The figure-of-merit was explained in section 2.0..

3.1 NON-STAGGERED GEOMETRY

The non-staggered geometry is pictured in Figure 3.1. The important measures for this geometry are,

Cluster Area = 9

Aspect Ratio = 1:1

Figure-of-Merit = 0.1092.

Of the four geometries, this geometry has the worst figure-of-merit. This is due to two factors. The first is the larger cluster area. The second is the cluster shape. The normalized moment will be highest for a circle. If the cluster area closely resembles a circle, the figure-of-merit will be high. The square cluster area of the non-staggered geometry does not resemble a circle.

3.2 REGULAR HEXAGONAL

The regular hexagonal geometry is pictured in Figure 3.3. The important measures for this geometry are,

Cluster Area = 6.06

Aspect Ratio = 1:0.866

Figure-of-Merit = 0.1630.

Of the four geometries, this geometry has the best figure-of-merit. This is due mainly to the close resemblance the cluster area has to a circle. One disadvantage is that the aspect ratio is not 1:1.

3.3 STRETCHED HEXAGONAL

The stretched hexagonal geometry is pictured in Figure 3.2. By stretching the regular hexagonal geometry, a 1:1 aspect ratio is achieved. The important measures for this geometry are,

Cluster Area = 7

Aspect Ratio = 1:1

Figure-of-Merit = 0.1406.

3.4 STAGGERED SQUARE

The staggered square geometry is pictured in Figure 3.4. The important measures for this geometry are,

Cluster Area = 7

Aspect Ratio = 1:1

Figure-of-Merit = 0.1413.

The figure-of-merit for the stretched hexagonal and the staggered square geometries are essentially the same.

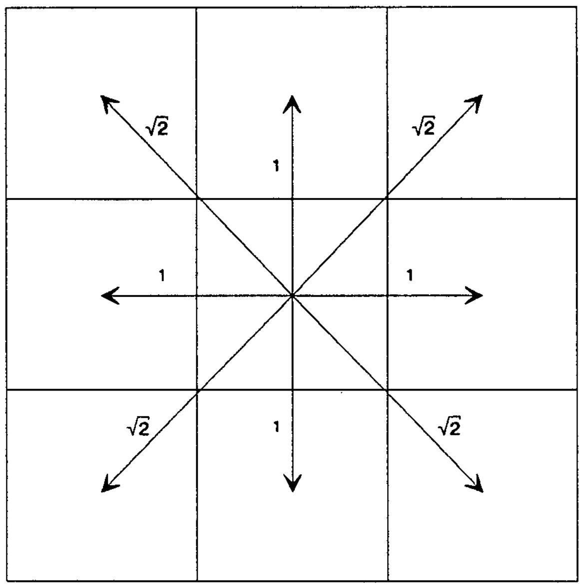

Figure 3.1 Non-Staggered Pixel Geometry.

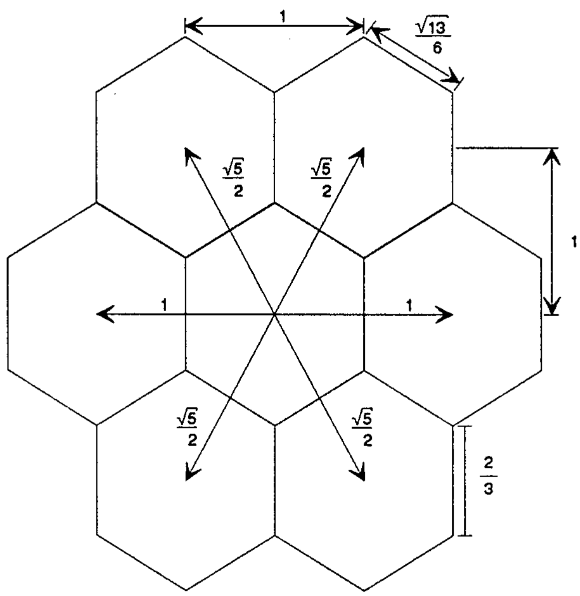

Figure 3.2 Stretched Hexagonal Pixel Geometry.

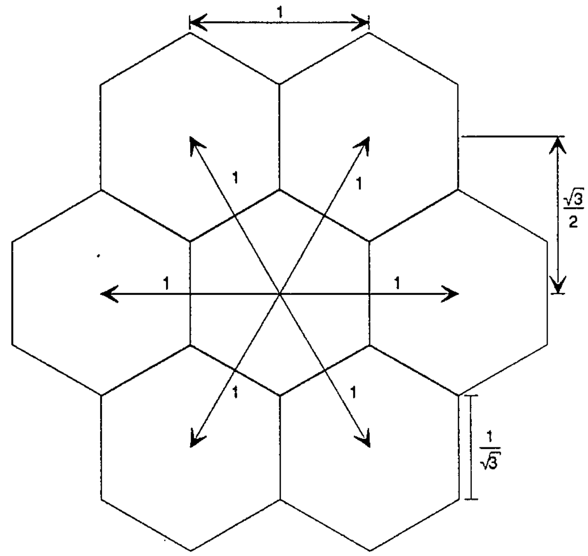

Figure 3.3 Regular Hexagonal Pixel Geometry.

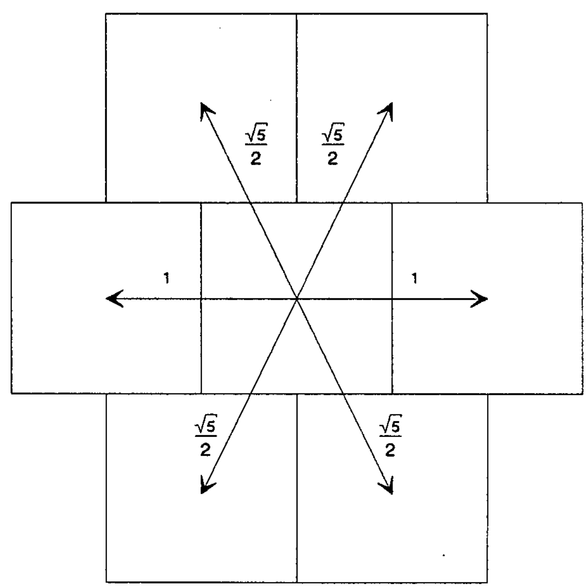

Figure 3.4 Staggered Square Pixel Geometry.

4.0 MAPPING FUNCTIONS

Now that the geometries have been clearly defined, it is possible to derive mapping functions that will map one geometry into any other geometry. Three mapping functions will be investigated. The three mappings operate at the lowest level and must be applied to the pixels prior to entering the SP. These three are direct mapping, half-step mapping and quarter-step mapping. Direct mapping also involves a post-processing step to shift centroids and reduce offset errors.

The half-step and quarter-step algorithms alter the pixel intensities in an attempt to take a staggered FPA pixel stream and produce a pixel stream that would be identical to the output of a non-staggered FPA viewing the same scene. Because the field of view for a staggered FPA is slightly larger than the field of view for the non-staggered array, the mapped output must be either left, center or right aligned in the non-staggered FPA field of view. Left or right alignment results in half-step mapping. Center alignment results in quarter-step mapping.

One problem with all mapping methods is that they map one geometry into a geometry with a lower figure-of-merit. Because of this, the resolution in the mapped image is lower. The consequence of this is that closely spaced objects (CSOs) will have a greater tendency to merge. This trait is not due to the mapping but rather is due to the lower figure-of-merit for the target geometry. If the CSOs were viewed using an FPA with the same target geometry, the CSOs would have the same tendency to merge. CSO merging also appears to be dependent on object size. Point source CSOs have a greater tendency to merge than blur spots.

4.1 DIRECT MAPPING

Direct mapping is the most easily implemented. If the pixels are allowed to pass into the SP with no modification, the result is direct mapping. The maximum centroid shift is one half of a pixel width. By post processing the reported centroids, a maximum centroid shift of one quarter pixel can be obtained. Because point objects remain point objects under direct mapping, it is the least desirable in terms of small object centroid shifting and object merging. For blur spots, the shifting and merging effects are less pronounced. Direct mapping does not, however, degrade the SNR.

A mathematical description for direct mapping can be developed. Figure 4.5 shows the output from a staggered array that has been illuminated by an object with an area of approximately one pixel. Figure 4.6 shows the output after the application of direct mapping. Figure 4.7 shows the mapping function required to transform the intensities in Figure 4.5 to the intensities in Figure 4.6. Because the impulse functions in the mapping have unity value, no additional hardware is required to implement direct mapping. The mapping shown in Figure 4.7

assumes that a constant quarter pixel shift has been added to the reported centroids. This can easily be done by the object processor.

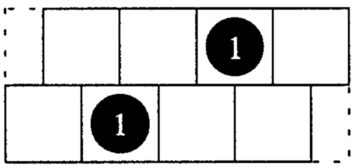

Figure 4.5 Intensities on Staggered Array.

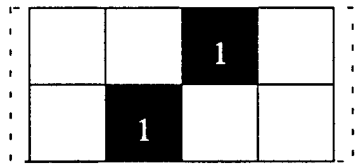

Figure 4.6 Result of Direct Mapping

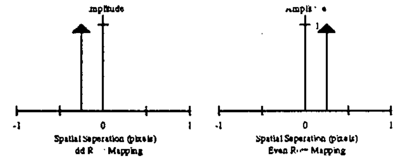

Figure 4.7 Direct Map

4.2 HALF-STEP MAPPING

In this discussion, the left aligned case has been chosen. The right aligned follows directly from this discussion.

Left alignment requires that rows offset from the left be shifted one half of a pixel width to the left. Unlike direct mapping, the shift must be performed so that the intensity information is correctly mapped into the left aligned position. Figure 4.1 shows the same object positions as Figure 4.5 except that the object intensities will now be partitioned onto a non-staggered arrangement. Figure 4.2 shows the resulting non-staggered intensities. Figure 4.3 is the mapping required to map the staggered array intensities from Figure 4.5 into the left-aligned non-staggered intensities of Figure 4.2. The rows that are offset from the left side of the field of view are moved left by an averaging function defined by the mapping. The rows already left aligned are not effected. This shown by the unity impulse mapping.

To implement this mapping, some hardware is needed. At least one multiplier and one adder will be required. Some additional circuitry to keep track of the row count is also necessary.

For point source objects, the resulting pixel stream is identical to the case of viewing the scene with a non-staggered array. Notice that this statement assumes that the pixel response is spatially uniform. The maximum centroid shift is less than in the direct mapping case because one of the point sources has been spread by the low-pass mapping function.

For blur spots, it appears that the mapping is not an exact representation of non-staggered viewing. This is most likely due to more exact spatial pixel response characteristics in the blur spot simulation models. The mapping does degrade the SNR because the peak intensity can be spread over multiple pixels.

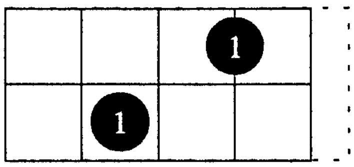

Figure 4.1 Illumination of Left-Aligned Array.

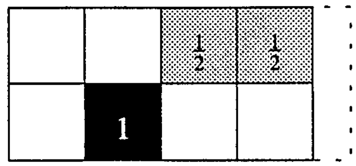

Figure 4.2 Left-Aligned Resultant Intensities

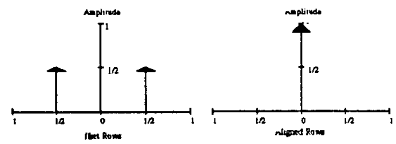

Figure 4.3 Half-Step Map

4.3 QUARTER-STEP MAPPING

Quarter-step mapping is similar to half-step mapping except that the non-staggered view is center aligned in the staggered field of view. This alignment requires the shifting of both odd and even rows. Each row will be shifted toward the center by one quarter of a pixel width. This shift must also be done with the correct intensity mapping. Figure 4.4 shows the object illumination and Figure 4.5 shows the resultant intensities. This resultant can be achieved by using the mapping of Figure 6.1. The same hardware required for half-step mapping would be required for quarter-step mapping.

Again, for point source objects, the resulting pixel stream is identical to the case of viewing the scene with a non-staggered array. For larger objects, however, the resultant intensity map will undergo some spreading. The spreading is not as pronounced as in the half-step case. This is due to a slower frequency domain roll-off for this mapping. Thus, the SNR degradation for quarter-step mapping is not as bad as the half-step mapping case.

Simulations show that the error for quarter-step mapping is similar to the error obtained in half-step mapping. This error is less than one tenth of a pixel width in both cases.

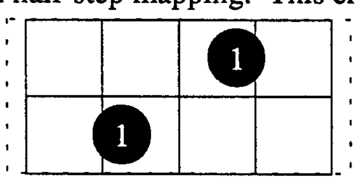

Figure 4.4 Illumination of Center-Aligned Array.

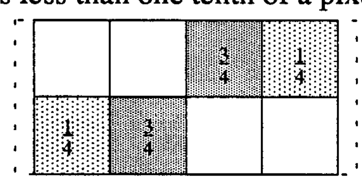

Figure 4.5 Center-Aligned Resultant Intensities

Figure 4.6 Quarter-Step Map

5.0 BLUR SPOT OBJECTS

Based on preliminary simulations, there is some object spreading and SNR loss for the half-step and quarter step filters. One possible option is to use direct mapping in conjunction with an OP algorithm. Direct mapping requires no hardware modifications and does not spread the object or degrade SNR. Direct mapping can cause CSO merging.

The OP algorithm essentially adds a quarter pixel width offset to all centroid measures. The reason for this offset is that the direct mapping subtracts one half of a pixel width from every other row. By adding one quarter of a pixel width to every row, the total shift for any single row is less than one quarter of a pixel width. Simulations for a set of randomly placed blur spots show that the maximum centroid error is less than one tenth of a pixel width. The results of the simulation are shown in Figure 5.1.

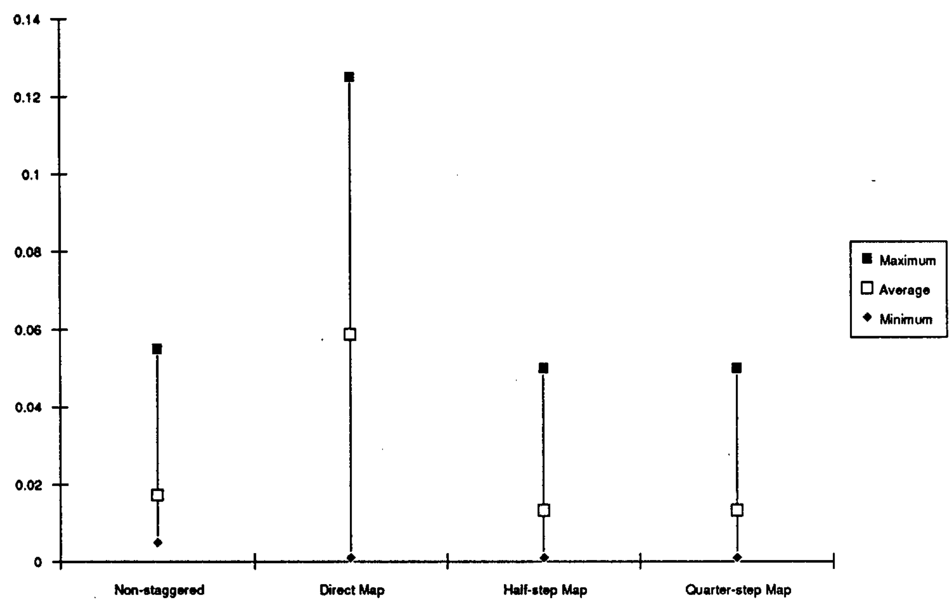

Figure 5.1 Graph of Centroid Errors versus Mapping Method for a Random Set of Blur Spots

6.0 CONCLUSION

The results of this report are believed to be accurate, however, they should be viewed as preliminary results. Neither the time nor the money was available to undertake exhaustive simulations. The simulations presented here did not include the spatial filtering function. This function could have a significant impact on the results. Extensive simulations should be carried out before the algorithms or methods present in this report are adopted or deployed.

The resolution of the non-staggered geometry is not as good as the staggered geometries so that some object merging is unavoidable. For purely SP based mapping, the quarter step mapping approach offers the best trade-off between object merging and SNR. The direct mapping approach offers the best SNR but has a greater propensity to merge objects.

The recommended approach for SP testing is to use the direct map and the OP algorithm. This approach does not require any additional hardware and for the current generation clustering and centroid chips will not introduce errors in the reported centroid. There is some possibility for object merging that can only be settled by further simulations.